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Research article

A framework to assess landscape structural capacity to provide regulating ecosystem services in West Africa

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ABSTRACT

The Sudanian savanna landscapes of West Africa are amongst the world's most vulnerable areas to climate change impacts. Inappropriate land use and agriculture management practices continuously impede the capacity of agricultural landscapes to provide ecosystem services (ES). Given the absence of practical assessment techniques to evaluate the landscape's capacity to provide regulating ES in this region, the goal of this paper is to propose an integrative assessment framework which combines remote sensing, geographic information systems, expert weighting and landscape metrics-based assessment. We utilized Analytical Hierarchical Process and Likert scale for the expert weighting of landscape capacity. In total, 56 experts from several land use and landscape management related departments participated in the assessment. Further, we adapted the hemeroby concept to define areas of naturalness while landscape metrics including Patch Density, Shannon's Diversity, and Shape Index were utilized for structural assessment. Lastly, we tested the reliability of expert weighting using certainty measurement rated by experts themselves. Our study focused on four regulating ES including flood control, pest and disease control, climate control, and wind erosion control. Our assessment framework was tested on four selected sites in the Vea catchment area of Ghana. The outcome of our study revealed that highly heterogeneous landscapes have a higher capacity to provide pest and disease control, while less heterogeneous landscapes have a higher potential to provide climate control. Further, we could show that the potential capacities to provide ecosystem services are underestimated by 15% if landscape structural aspects assessed through landscape metrics are not considered. We conclude that the combination of adapted land use and an optimized land use pattern could contribute considerably to lower climate change impacts in West African agricultural landscapes.

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1. Introduction

Growing international research efforts have focused on the protection of biodiversity and ecosystem services (ES) in response to decreasing resilience of land systems towards climate change (CC). After releasing the Millennium Ecosystem Assessment (MEA) report in 2005, several countries across Europe and America institutionalized policy frameworks to identify, map, monitor, and evaluate the changing pattern of ES and biodiversity degradation across different scales (see Maes et al., 2016; IPBES/4/8). The assessment frameworks and standards defined by MEA[1] or TEEB[2] and Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) provide guidelines for how the value of nature and different ecosystems from different landscapes

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[1] Millennium Ecosystem Assessment (MEA) (Source: http://www.millenniumassessment.org/en/index.html).
[2] The Economics of Ecosystems and Biodiversity (TEEB) (Source: http://www.teebweb.org/).

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can be assessed (Fürst et al., 2012). Intergovernmental mapping and assessment through IPBES helps to standardize and further develop methods, frameworks, and assessment tools for an efficient mapping and assessment of ES for developed and developing countries.

Specific attention has been paid to studies with focus on forest ES, urban and rural ES, as well as river and watershed ecosystems with limited focus on ES provided by agricultural landscapes (Leh et al., 2013; Boafo et al., 2015; Sinare et al., 2016). Studies on agroecosystem services have focused on provisioning services (Huang et al., 2015), while regulating services have been narrowly studied within the past decade (Burkhard et al., 2015). Focusing on agricultural landscapes, Dale and Polasky (2007) and Reyers et al. (2010) found multiple interrelationships between agricultural management practices and ES provision. They found that the attraction of pollinators across agricultural lands increases crop yields thus serving as a provisioning service. Relatedly, crop diversification as a farm management approach in developing countries resulted in a mean increase in crop yield by about 79 percent (Pretty et al., 2006). Nonetheless, no study exists to explore the potential trade-offs of this management practice on the provision of other related agroecosystem services such as flood control. Most scientific studies frequently estimated ES provisioning capacities by scaling up the results from single ecosystems or land uses, while the question of how to optimally structure land uses in agricultural landscapes is only rarely studied (Frank et al., 2014). The argument that regulating ES such as flood mitigation and water erosion control are determined by landscape structural characteristics such as configuration, size, and the form of the land use classes is not new (Goldman et al., 2007; Fürst et al., 2016). However, research on the dependence of regulating services related to CC and how the resilience of land systems can be improved through "optimal" restructuring of land uses and other landscape elements is missing (Bennett et al., 2009; Fürst et al., 2012).

Many studies have introduced several assessment methods which utilizes land use types as clues for ES provision due to their proximity to human settlements (Chan et al., 2006; Ruhl, 2016). Troy and Wilson (2006) used land cover classes to account for the connectivity of settlement clusters to other land use classes. In South Africa, Egoh et al. (2008) combined maps of soil erosion potential and vegetation cover to create a map of soil retention as a proxy for assessing regulating services. Burkhard et al., 2009, 2015 utilized an assessment matrix to link land cover information obtained from remote sensing and GIS with expert interviews. Busch et al. (2012) argued that though these approaches provide an understanding of the nature of ES provisioning from different land cover types, they have been criticized for not being reliable due to the limited knowledge and objectivity of the expert involved. In recent publications, Baral et al. (2013) and Jacobs et al. (2015) employed quantitative and qualitative approaches to assess uncertainties aimed at minimizing experts subjectivity of the assessments. The use of landscape metrics (LM) as a proxy for assessing ES provisioning capacities at the landscape scale has only recently experienced attention (Fürst et al., 2010a,b; Frank et al., 2012a,b; Syrbe and Walz, 2012). To assess the impact of the landscape structure on the provision of landscape aesthetics as a cultural service, Frank et al. (2012a,b) found that without including landscape metrics in the assessment process, the actual potential of the poorly structured agricultural landscapes of the Region of Saxony, Germany, would be over-estimated in a practical landscape planning context. In Jordan, Albalawneh et al. (2015) combined the LM approach with Analytic Hierarchy Process (AHP) to prioritize and assess potential agricultural landscape sites suitable for water harvesting.

In West Africa (WA), increasing population, urbanization, extensive instead of intensive agricultural practices, poor land use planning, and land management strategies continuously jeopardizes sustainable ES provision. The reliance on primary agricultural production for consumption and livelihood sustenance combined with extreme CC impacts requires a pragmatic approach for spatial explicit mapping. The focus reflects the status and potential loss of ES provisioning capacities in this region and suggests alternative landscape and farm level management options to support decision-making in agricultural systems (Swinton et al., 2007; Crossman et al., 2012; Frank et al., 2012a,b; Callo-Concha et al., 2013; Singh, 2013; Schulp et al., 2014; Burkhard et al., 2015; Inkoom et al., 2017a). Nonetheless, the stifling scientific progress which challenges mapping and assessment of ES in WA is caused by lack of appropriate data resulting in uncertainty and qualitatively poor assessment results (Eigenbrod et al., 2010; Forkuor et al., 2014; Inkoom et al., 2017b).

This paper introduces a semi-quantitative ES assessment framework that combines expert knowledge on land use and land management with landscape metrics assessment adapted to the specific case of West African agricultural landscapes. Due to the extremely small patches and very heterogeneously mixed cropping systems, the usability of metrics developed for European or North-American agricultural landscape to these landscapes are usually questionable. The underlying assumption of our case study was that the more heterogeneous an agricultural land use pattern is, the higher the landscape's capacity level to provide regulating ecosystem services and to enhance the land systems resilience towards CC. Further, we tested our assessment of landscapes' capacity to provide regulating ES with and without the influence of landscape structure under two landscape resilient scenarios. Our assessment was based on the GISCAME,[3] a framework that facilitates the development of land use/land cover change scenarios together with experts or based on transition probabilities (Fürst et al., 2010a,b; Frank et al., 2013). GISCAME includes a set of landscape metrics to assess fragmentation, connectivity and landscape diversity as criteria that might affect landscape capacities to provide ES (Frank et al., 2010, 2012a,b; 2013; Koschke et al., 2012, 2013). We adapted the inherent evaluation bases for ES assessments by local expert knowledge including an appraisal of the uncertainties of this information. **We implemented this framework within the context West African Science Service Center on Climate Change and Adaptation Land Use (WASCAL) project with the aim of providing technical and practical recommendations to farmers and planners amidst continues climate change impact.** Finally, we discuss lessons drawn from our case study as a pioneering research in WA.

2. Methods

2.1. Conceptual framework

By this framework, we seek to express essential methodologies applicable for ES assessment in our case study location as a means to improve the reliability, validity, and replicability of our methods and results to other domains of assessment. Our proposed assessment framework combines independent methodologies in a systematic order to arrive at the overall goal assessing the landscapes capacity to provide ES. The framework is in three main components: identification, quantification, and appraisal. Though the components presented here are separate, a key feature in the main framework is the interrelationships and interdependencies. While

[3] Geographic Information System Cellular Automaton Multi-criteria Evaluation (GISCAME) formerly known as "Pimp Your Landscape" – (Source: http://www.giscame.com/giscame/english.html).

no strict order of implementation in the proposed methods exists, we recommend the stepwise order in Fig. 1 as a guide on landscapes where baseline information or similar approaches on ES assessments are unavailable.

In the first component, we sought to identify which ES exist on our landscape and how they affect human welfare and environmental sustainability. The objectives and goals for identifying the ES must correspond to a broader discourse of their availability and accessibility, and how they change the landscapes' character under different management practices. Lastly, how ES provide landscape resilience in the phase of changing climate change was considered. The process of ES identification in this context can be facilitated through biophysical modelling or stakeholder consensus (Fürst et al., 2010a,b; Burkhard et al., 2015; Maes et al., 2016). However, for the purpose of this specific framework, expert stakeholder identification was preferred due to the absence of reliable spatial data required for biophysical modelling. The final identification and selection of specific ES categories was based on locational relevance of the ES and stakeholder consensus. In our specific case, we focused on the interaction between landscape pattern and structure and the role agriculture landscape management plays in shaping the landscape structure as critical in the overall ES identification process.

In the second component, we focused on quantitative and qualitative methods for assessing the identified ES under the previous component. The inclusion of stakeholders or expert with requisite knowledge on the ES concept and research area in the qualitative approach was highly preferred. Although this approach was favored for its limited data demands, a generally medium to high spatial resolution remotely sensed data classified for the landscape under study is required to facilitate the process. In the event where spatial data is unavailable, neutral landscape models could be used as alternatives to test hypothesis of several landscape structural configurations and their influence on the topic under study. Methods such as Likert scale and Analytical Hierarchical Process (AHP) were preferred due to their extensive application within ES literature (see Burkhard et al., 2012; Koschke et al., 2012). Quantitatively, it is feasible to use landscape metrics (LM) to assess the role structural configuration plays in the landscapes' capacity to provide ES (Fürst et al., 2010a; Frank et al., 2012a,b). Our proposed framework utilized GISCAME as an integrative tool to connect expert evaluation with LM for the structural assessment. This was possible through the multicriteria evaluation and landscape structural modules implemented in the GISCAME toolsets.

The final component, referred to as appraisal component, combines, and applies the first two components within a specific landscape management regulation and or planning scheme. Here, the variabilities presented by the landscapes' character and or details of the planning context could differ and might greatly influence the first two components. The implication of the assessment outcome for policy options and decision-making was a guiding principle. For the purpose of this study, we applied our framework to facilitate agricultural land management and landscape resilience. In the following sections, we present how our proposed framework was applied in our case study area.

2.2. Case study region

Our case study region (Fig. 2a) was the Vea catchment composed of two administrative zones: Bolgatanga Municipal and Bongo districts in the Upper East Region, Ghana. The study region covers an area of about 1200 km^2 characterised by an average elevation less than 300 m (Farr and Kobrick, 2000) with slopes rarely exceeding five degrees (Forkuor et al., 2014). The mean annual rainfall is about 950 mm with maximum temperature of about 45 °C between March and April, and minimum temperatures of 12 °C in December with erratic rainfall patterns leading to crop failures and income losses (Antwi-Agyei et al., 2012; Forkuor et al.,

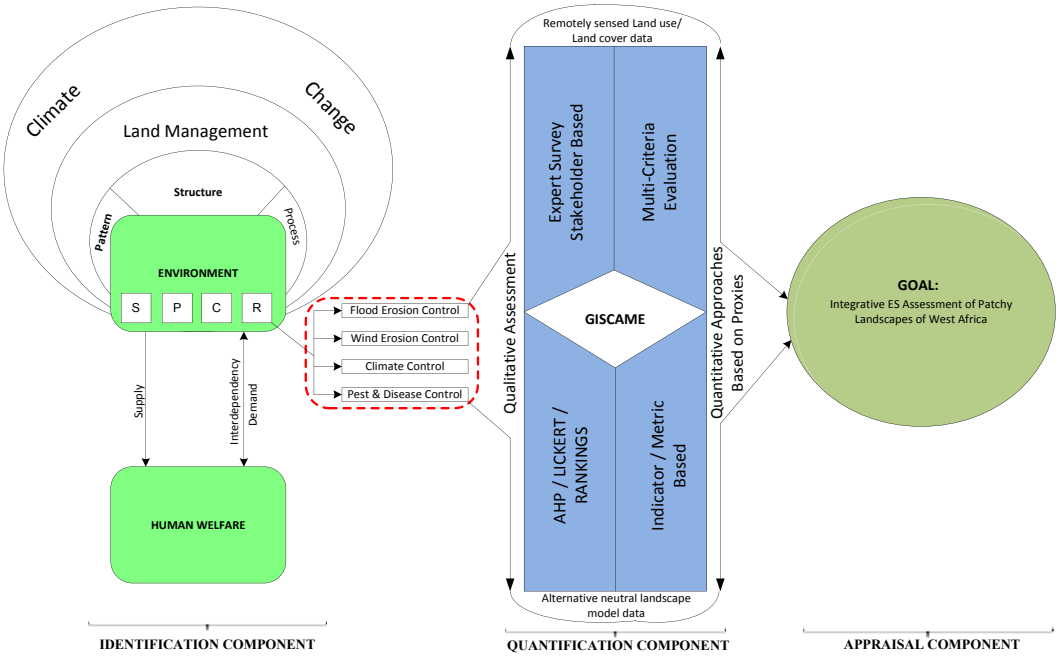

Fig. 1. A conceptual framework for assessing landscape structural impact on potential ES provision in Upper East Region, Ghana. Meaning of abbreviation(s): S – Supporting ecosystem service; P – provisioning ecosystem service; C – cultural ecosystem service; R – regulating ecosystem service. The identification of a selected set of ES could be based on literature or through stakeholder or expert recommendations (as highlighted in red dotted rings) solicited through interviews or focus group discussions. GISCAME presents an ultimate software platform to integrate both expert evaluation and structural assessment. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

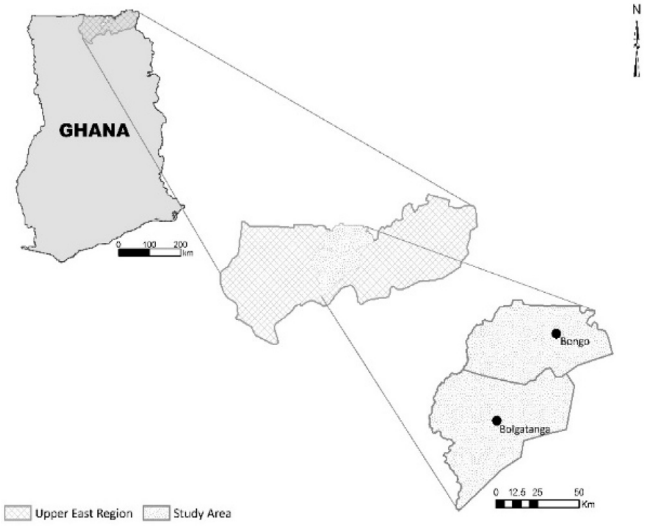

Fig. 2a. Location of study area.

Table 1
Land use classes and their descriptions.

No.	Land Use Class	Description
1	Water bodies	Reservoirs, Rivers and lakes
2	Millet	Areas primarily under maize cultivation
3	Maize	Areas primarily occupied by maize varieties
4	Rice	Irrigated farm fields
5	Groundnut	Area under groundnut cultivation; mostly intercropped with millet or maize.
6	Grassland	Areas covered by natural grass
7	Trees	Mainly trees
8	Mixed Vegetation	Principally trees with shrubs
9	Settlement	Permanently occupied by humans; partly rural and urban

2014). Between 2000 and 2010, a nine percent increase in population in the catchment area (Ghana Statistical Service (GSS), 2012), coupled with decades of climate variability impact, resulted in increased pressure on the landscape to provide relevant ES such as food, fodder, and water.

Agriculture is the main source of livelihood for settlers in the Vea catchment (GSS, 2007; Forkuor et al., 2014). Shallow and pebbly Leptosols occur in the elevated areas of Vea (Martin, 2006). Despite being weak in organic matter content and low on soil fertility, this soil type allows the cultivation of late millet and other crops that require relatively low soil fertility. Between 51% and 58% of the population in Bongo and Bolgatanga are working in agriculture (GSS, 2005). Crop cultivation takes place during the rainy season spanning from May to October, while irrigated agriculture is undertaken on a limited scale during the dry season from late October to April respectively. Traditional cropping systems include maize, millet, sorghum, and groundnut. The occurrence of fluvisols with high clay content allows for water logging during the rainy season and enables the cultivation of paddy rice.

2.3. Land use/land cover data

Land use/land cover (LUCC) data were based on RapidEye images, acquired in 2013 with a spatial resolution of 5 m through which nine land use types could be identified. The initial image preprocessing was undertaken using ENVI ATCOR (Forkuor et al., 2014). The nine land use types included groundnut, maize, millet, rice, grassland, mixed vegetation, trees, settlement, and water bodies (Table 1).

We selected four equally sized test sites namely Soe, Vea, Bolgatanga, and Bongo Town based on the criteria that 1) locations are typically heterogeneous with spatial representation of all land use classes and 2) locations are homogenous with limited representation of all land use types. Table 2 features key characteristics of the test sites while their location and land use compositions are displayed in Fig. 2b.

2.4. Generating alternative landscapes for scenario testing

The "Cellular Automaton" add-on in GISCAME facilitates the explorative scenario development through transition probabilities and neighbourhood interactions. The objective for using this module **in this section** was to increase heterogeneity and homogeneity of our inputs sites to help test our overall resilience scenarios (see Section 2.7). We used transition probabilities and neighbourhood conditions to specify and restrict target cells from further transformation. In the absence of statistical and land cover data to derive transition probabilities, we employed subjective expert opinion to derive and validate the rule set underlying our transition probabilities and neighbourhood condition (see Fig. 3). While most target land use types were kept from further transformation, the conditional clauses expressed under the neighbourhood functions facilitated the expression of a land use type as a constraints or catalyst for transformation. The output landscapes, from L1 to L4 (see Table 3 above), were exported as ASCII file (*.txt) to serve as input for our resilience scenario analysis.

Adapted land use development in GISCAME focuses on specifying neighbourhood influence on cell level transformation using conditional and relational clauses. From Table 3, millet cells have a 70 percent transition probability to transform into grassland cells if the neighbourhood cells of the input land use type have three or less grassland cells. If this condition is false, cell transformation will fail.

2.5. Assessment and mapping of ES using land use and land cover information

Amid multiple challenges to consult expert stakeholders during workshops, we conducted our constructive consultations mostly through bilateral discussions. In total, 56 representatives drawn from Town and Country Planning Department (TCPD), Forestry Commission (FC), Environmental Protection Agency (EPA), Ministry

Table 2
Characteristics of selected areas within study sites.

Selected Site	Site Number	Site Alias	Description of Area
Soe	1	L1	Extremely patchy with occasional connectivity into large patterns
Vea	2	L2	Extremely homogenous
Bolgatanga	3	L3	Partially homogenous
Bongo	4	L4	Extremely patchy/heterogeneous

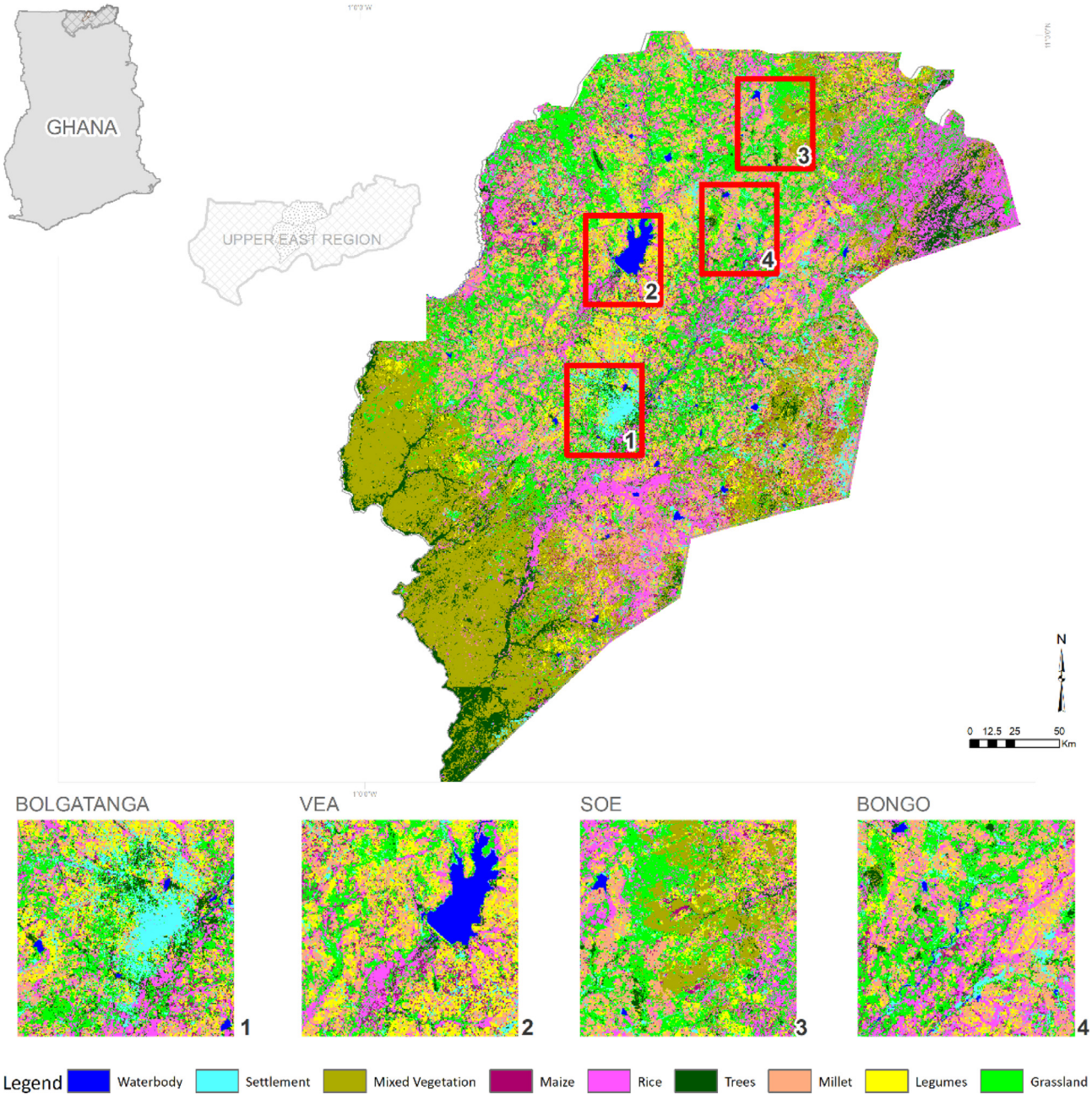

Fig. 2b. A 2013 RapidEye image land use classification for Bolgatanga and Bongo district in the Upper East region, Ghana. The red squares highlight the four selected areas for the case study. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

of Water Resources, Works and Housing (MWRWH), Ministry of Food and Agriculture (MOFA), and GIS expert from non-governmental organizations (NGO's), were invited to assess the capacities of 9 land cover types to contribute to regulating ES in the context of our study area. Expert consultation was organized as a one-time survey as it appeared more important to involve a large group (56 individuals) to explore their depth of knowledge and range of judgements rather than working with a smaller group in a Delphi approach.[4]

Our assessment focused on key regulating services which have the potential to be changed through management decisions, planning and policy directives (Fürst et al., 2016). They included wind erosion control, climate regulation, pest and disease control, and flood regulation (i.e. hazard mitigation) (see Table 4 for overview). Our final selection was based on recommendations from recent publications (Boafo et al., 2015; Inkoom et al., 2017a) and subsequent constructive consultations with our expert stakeholders. Following Burkhard et al. (2012, 2014, 2015), we asked our experts to assess the ES capacities using a 6-point Likert-scale from 0 = least (zero) capacities to 5 = highest capacities.

Additionally, we applied AHP to rank which of the four test areas (from L1 to L4, see Fig. 4) has the highest capacity to provide the

[4] The Delphi approach is a method widely used to gather data from respondents with knowledge in a specific area of expertise (Hsu and Sandford, 2007).

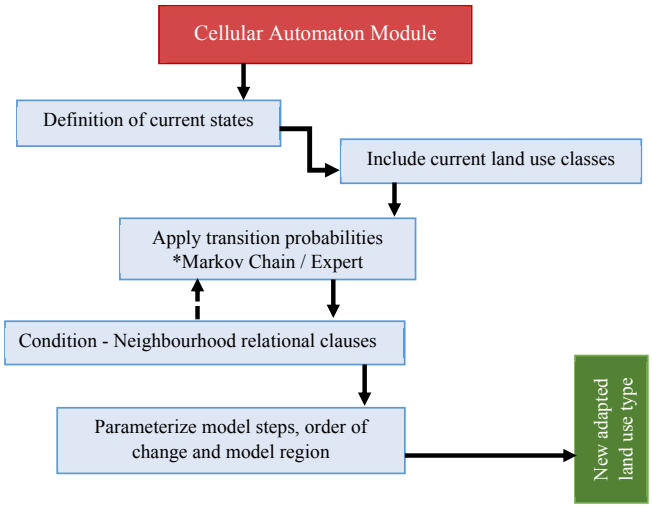

Fig. 3. A process framework for deriving adapted land use classes within the Cellular Automaton Module in GISCAME. A two-way interaction between the transition probability and application of neighbourhood conditions helps to eliminate redundancy in the expected pattern.

four ES. AHP (Saaty, 1977) is a multi-criteria decision-making approach that consults experts in a pairwise comparison to prioritize decision alternatives. In this case, we used a scale ranging from 1 to 9, where 1 indicates equal preference to the issue under evaluation and 9 indicates absolute preference of one landscape over any other (Saaty, 1977). We calculated AHP weights using AHPCalc (Goepel (2016), http://bpmsg.com/academic/ahp-news.php) to obtain a consistency index as a yardstick for coherence of comparison. Finally, we asked our experts to evaluate their own level of uncertainty in their judgements on a scale from 0 (very uncertain) to 100 (very certain).

2.6. Overview of linking ES and LM

The development and advancement of LM indicators to capture and assess the relevance of the spatial structure to ES assessment has been highly emphasized in ES literature (see Burkhard et al., 2012). A vivid theoretical background and framework towards linking landscape metrics to ES has been provided in Frank et al. (2012a,b). Further, Syrbe and Walz (2012) presented a detailed list of some ES and suggested specific LMs for analyzing them. For instance, to assess a regulating service like erosion control, the authors recommended the use of effective mesh size and edge density.

We employed the LM approach to understand how landscape potential capacity values increases or decreases relative to the regulating ES under assessment. Unfortunately, research on identifying core LM which discriminate the patchy character of the landscapes in the study area is deficient. Until recently, Inkoom et al. (2018) in a case study from Bolgatanga and Bongo, identified and proposed Landscape Patch Index (LPI), Area-Weighted Mean Shape Index (AWMSI), Cohesion, Effective Mesh Size (MESH), and Aggregation Index (AI) as core LM to measure landscape heterogeneity with the aid of Fragstats v4.2. Nonetheless, this study focused on the preexisting landscape metrics in the LSM Module in GISCAME. GISCAME utilizes Shape Index (SHAPE) to express naturalness, while Shannon's Diversity Index (SHDI) and Patch Density (PD), all measured at the landscape scale, were implemented for landscape diversity assessment (Frank et al., 2013).

We applied the qualitative routines developed by Fürst et al. (2012) and Koschke et al. (2012) for adapting LM values to ES provision in GISCAME. Several assumptions regarding which land use class qualifies to be categorized into natural and semi-natural areas must be considered for the ES and LM linkage (Frank et al., 2013; Tveit et al., 2006). From Table 5, the following LM criteria pre-integrated in GISCAME were followed.

Stage A Input land cover classes were clustered to reflect natural or semi-natural classes in accordance with the concept of "hemeroby" (see Walz and Stein (2014) for writings on the concept of Hemeroby). The Hemeroby concept refers and it application to ES refers to the extent to which humans impact ecosystems (Blume and Sukopp, 1976; Sukopp, 1976). A complete classification of 'hemeroby' classes from the study location is provided in Table 6.

Table 3
Rule set for developing adapted land use classes in GISCAME.

Year 2013	LUC Transitions		
	Adapted land use scenario		N
LUC	Target LUC	P (%)	Condition
Legumes	Millets	90	Millets ≥ 3
Rice	Maize	75	Maize > 4
Grassland	MV	75	MV < 1
Millet	Grassland	70	Grassland ≤ 3
Maize	Rice	70	Rice > 5
Mixed Vegetation	Tree	80	Tree > 3
Settlement	Millets	50	Millets ≤ 2
Trees	Legumes	75	Legumes > 4

LUC - Land Use/Land Cover Type; CS – Complex Scenario; N - Neighbourhood.

Table 4
Definition of selected ecosystem services and their relationship to land use types.

Selected Ecosystem Service	Definition	Relationship to land cover
Regulating Ecosystem Service	Climate Regulation	Alterations in land cover potentially impact local temperature, precipitation and energy
	Wind Erosion Control	Presence of deep rooted cultivated or natural land cover affect the extent of wind erosion impacts as well as.
	Pest & Disease Control	Highly intensified agricultural landscape with diversity of crops prevents the spread of pest and diseases.
	Flood Regulation	Land use cover aids soil retention

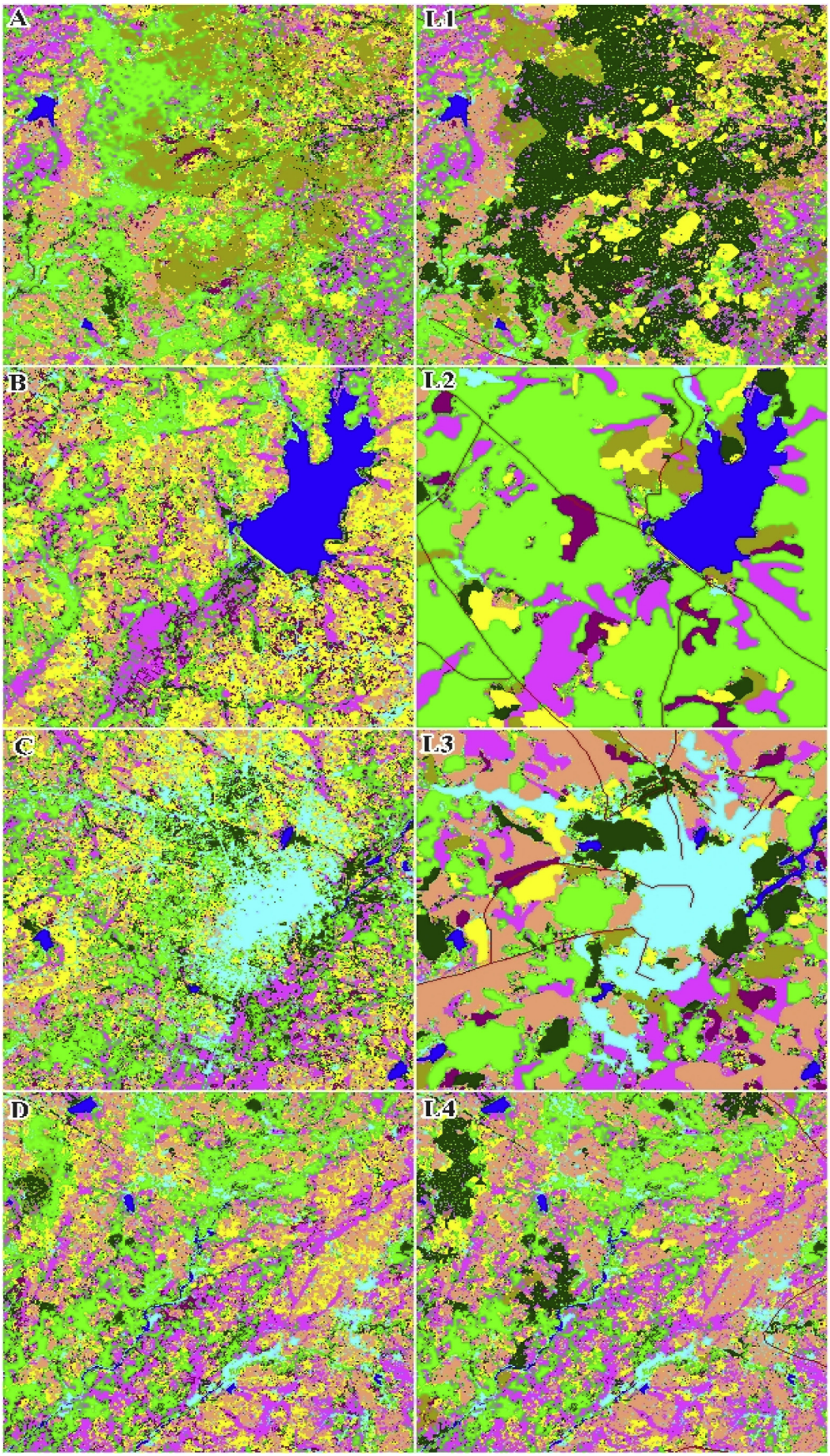

Fig. 4. Constellation of real and modified landscapes for ES assessment. Left: A - Soe, B – Vea, C - Bolgatanga, D - Bongo. Right: L1 represent extremely patchy with occasional connectivity into large patches in Soe; L2 represent extremely homogenous areas in Vea; L3 represents partially homogenous area in Bolgatanga; L4 represents extremely patchy area of Bongo.

Table 5
Pre-installed LM in GISCAME for assessing relevant regulating ecosystem services in the case study area.

Regulating Ecosystem Service	Assessment Criterion	LM for assessment
Pest and Disease Control	Landscape Diversity	Patch Density Shannons Diversity Index
	Habitat Connectivity	Cost-distance Analysis
Flood Control	Landscape Fragmentation	Effective Mesh Size
	Near to Nature	Shape Index
Climate Regulation	Landscape Diversity	Patch Density
	Near to Nature	Shannons Diversity Index
Wind Erosion Control	Landscape Diversity	Patch Density
	Landscape Fragmentation	Effective Mesh Size

Following Frank et al. (2013), a three stage approach was pursued.

In all, three predominant hemeroby classes characterised our study area. The settlement class such was the only Euhemerobic class, signifying areas with very strong human impact. The dominant classes were classified under Ahemerobic and Mesohemerobic classes representing areas with almost no and moderate human impacts respectively.

Stage B Following Fürst et al. (2010a,b, 2012) and Frank et al. (2012a,b, 2013), landscape metrics indicators in GISCAME module were qualitatively translated on a five point impact scale (Metzger et al., 2006; see Table 7 for full description) and merged using the ecological connection matrices (Bastian and Schreiber, 1999). To assess the role landscape diversity plays in pest and disease control from a landscape structural perspective, we combined connectivity and patch density metrics as proxies. Syrbe and Walz (2012) proposed edge density and contrast, effective mesh size and slope length as amongst the metrics for assessing erosion prevention. In the absence of slope length and edge contrast, we combined density and mesh size as proxies for assessing erosion prevention/control for our specific case.

In other scientific undertakings where laws, regulations, or management strategies are present, they could serve as basis to determine thresholds in the impacts point in Table 7. However, due to lack of laws or formal agricultural management strategies, experts and outcomes of a quantitative assessment of LM in Fragstats influenced our classification.

Stage C Here, we evaluated the potential of each land use type to produce regulating ecosystem services using a 0 to 100 point scale (Koschke et al., 2012; Frank et al., 2013). Details are provided under section 2.5. The impact of incorporating the LM assessment on ES provision within GISCAME were later investigated.

Table 6
WASCAL Land Use Type (LUT) and associated groups specified in GISCAME. **Group, hemeroby classes and diversity group are land use type preconditions to be defined within GISCAME ahead of the main landscape structural assessment**.

Group	Land Use Types	Hemeroby Class	Diversity Group
1	Unproductive/Settlement	Euhemerobic	1
3	Rice	Mesohemerobic	2
6	Millets	Mesohemerobic	2
_	Legumes	Mesohemerobic	2
_	Maize	Mesohemerobic	2
7	Tree	Ahemerobic	3
9	Mixed vegetation	Ahemerobic	1
10	Grassland	Ahemerobic	1
15	Water body	Ahemerobic	1

2.7. Scenario testing for landscape resilience

Landscape diversity plays a key role in providing resilience. Hence, we sought to know how much diversity would be relevant to ensure landscape resilience. Here, an assessment of landscapes' capacity to provide regulating ES was evaluated with and without the influence of landscape structure (using LM) under a landscape resilient scenario. In the context of this research, two scenarios in relation to our initial assumption were developed (see Table 8a). In a broader context, outcomes of the scenarios when tested are to inform ongoing research aimed at encouraging agricultural landscape management alternatives in the phase of CC within the West African Science Service Center for Climate Change and Adaptive Land Use (WASCAL) Project. The first Landscape Resilience 1 (LR-1) scenario was developed to include a maximum share of non-consumable land use classes. By non-consumable classes, we mean land use types which are not directly consumed as food crops. Since non-consumable classes occupy more than 30% share of the study area, exploring their role in landscape resilience is extremely important. The second Landscape Resilience 2 (LR-2) scenario featured both consumable and non-consumable land use classes but with limited share of settlement classes. Settlement classes under this scenario were minimized for a strategic reason. This is because, amongst all four test sites, Bolgatanga had about 20% share of settlement classes while the other three sites head less than two percent share of settlement classes each.

In the absence of regulations and policies towards landscape management, we expect our outcomes to initiate a change in paradigm and inform policy concerns for ES derived from agricultural landscapes in the study region. The key characteristics of the scenarios are described in Table 8b below.

2.8. Statistical analyses and visualization of results

We employed a non-parametric method, Kruskal-Wallis equality-of-populations rank test (McDonald, 2009), to understand if a significant difference or similarities amongst the four landscapes might have influenced expert's decision. This assessment was performed on the outcomes of the Likert-scale rankings. This assessment was undertaken using the '*kwallis*' syntax in Stata 13.

GISCAME, a new replacement to 'Pimp Your Landscape' (Fürst et al., 2010a,b), was used to visualize expert assessment of the impact of differences in landscape pattern and their impact on ES. GISCAME combines a cellular automaton with GIS features and a multi-criteria assessment approach allowing users to assess and visualize the impact of changes in land use patterns on ecosystem services in a real time fashion. To do this, we entered values obtained from experts as required to ensure the different landscape become resilient in the phase of producing all four regulating ES. The outcome is visible through radar charts, which depicts the overall results.

3. Results

3.1. Outcome of the AHP process

In the assessment of AHP, a logical rationality drawn from the responses of the assessment into a consistency factor is relevant.

Table 7
Five point scale for translating LM metrics into structural impact levels for GISCAME.

Impact Point across metrics	Description	Relevance for ES
−10	Highly negative impact	Completely hinders the provision of a service
−5	Negative	Partially hinders the ES provision
0	Neutral/No impact	No significant impact
5	Positive	Partially favours and aids
10	Highly Positive	Completely aids the ES provision

According to Saaty (2005), a factor value equal to or lower than 0.1 (consistency level less than 10%) is satisfactory. Consistency value of derived from stakeholder assessment on climate regulation was 0.5% with 87.6% consensus. In the case of flood control, a consistency ratio of 0.1%, with 81.7% consensus was derived. For pest and disease control, a consistency ratio of 0.1%, with 83.8% consensus was deduced. A consistency ratio of 0.2%, and a consensus value of 82.2% was derived for wind erosion ecosystem service.

All consensus values observed throughout the four levels of ecosystem services assessment suggest strong coherence in the stakeholder assessment with somewhat less variability in the responses. In identifying which landscape contributed most to the rankings by way of weighting under each ecosystem, we found that L3 and L4 ranked first for wind erosion and pest and disease control respectively. For flood control and climate regulation, L3 was ranked first for both ecosystem services.

Table 9
Kruskal-Wallis equality-of-populations rank test.

L	Obs.	Rank Sum
1	56	6167.00
2	56	3415.50
3	56	6907.00
4	56	8710.50

Chi-squared = 61.722 with 3 d.f.; probability = 0.0001; Chi-squared with ties = 64.950 with 3 d.f.; probability = 0.0001.

3.2. Outcome of the Likert scale assessment

The general outcome obtained from the stakeholder weighting using Likert scale revealed a moderately strong prioritisation of L3 to provide pest and disease control, climate regulation, wind erosion control, and flood regulation. More specifically, for pest and disease control, L4 was highly prioritized. Again, in the case of flood regulation, L4 was highly prioritized, followed by L3, L2, and L1. Subsequently, the variance obtained for the assessment from Fig. 5 was highest for flood regulation under L4 and climate regulation under L2. The lowest variance values were recorded for flood regulation under L1, and climate regulation under L3 being the very lowest.

3.3. Statistical analysis

The principal use of the Kruskal Wallis test of rank (see Table 9) was to come to the determination of how the independent

Table 8a
Scenario development for exploring landscape resilience in the case study area.

Scenario	Description
Landscape Resilience 1 (LR-1)	Characterised by a greater share of mixed vegetation, grasslands, and tree as contributing land use classes to ES provision. Minimum share of legumes are represented.
Landscape Resilience 2 (LR-2)	Features an exceeding share of trees, mixed vegetation, water bodies, rice, legumes, with limited share of settlement land use classes.

Table 8b
Display of AHP outcomes including overall consistency ratios, weights, and highly ranked landscapes for all four regulating ecosystem services.

Ecosystem Service	Consistency Ratio (%)	Consensus (%)	Overall Weights (%)	Highly Ranked Landscape
Flood Control	0.1	81.7	38.0	L3
Pest Disease Control	0.1	83.8	33.7	L4
Climate Regulation	0.5	87.6	41.4	L3
Wind Erosion Control	0.2	82.2	33.3	L3

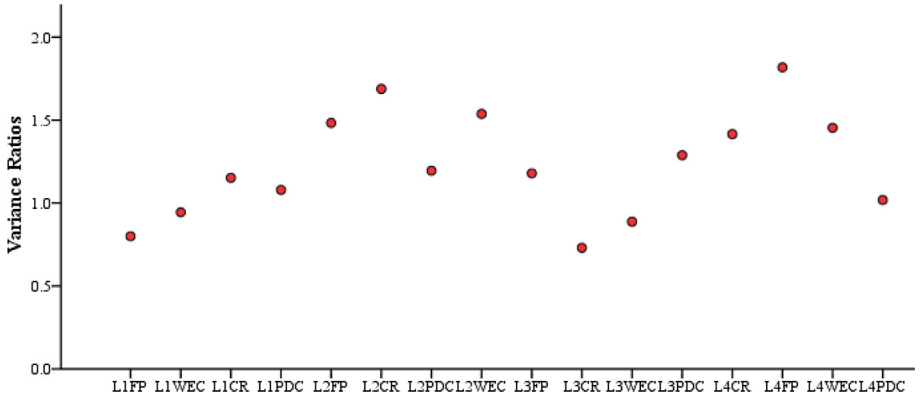

Fig. 5. Variance explained from Likert scale assessment on landscape capacities to provide 4 regulating ecosystem services. Abbreviation explained: L1 to L4 represent the different landscape sites; FP – Flood Protection; WEC – Wind Erosion Control; PDC – Pest and Disease Control; and CR – Climate Control.

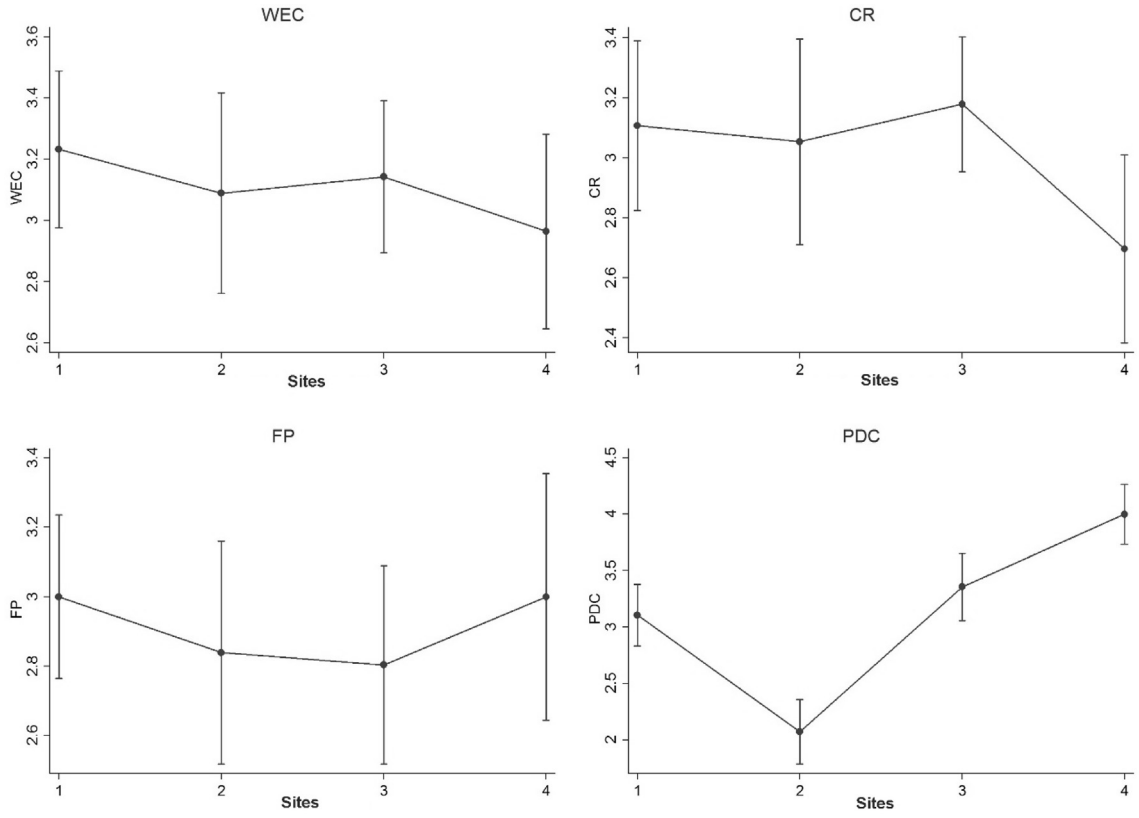

Fig. 6. Contrast of predictive margins of four landscapes on their contribution to the provision of ecosystem services. Abbreviations explained: FP – Flood Protection; WEC – Wind Erosion Control; PDC – Pest and Disease Control; and CR –Climate Control.

differences between landscapes L1 (n = 56), L2 (n = 56), L3 (n = 56), and L4 (n = 56) influenced their selection. All assumptions prior to the test were satisfied in Stata 13 (StataCorp, 2013). For this task, we hypothesized that the mean ranks of the four landscapes were the same.

Thus, a variation in the distribution of their means suggests a variation in their visual appeals; an expression of why respondents favors one landscape over the other in the provision of a particular service. A Kruskal-Wallis H test showed that there is a statistically significant difference in the landscape patterns of the four landscapes, χ^2 (2) = 64.950, p = .0001.

Fig. 6 represent a pairwise comparison of how each individual landscapes contributed to the overall assessment of the four ecosystem services to which they were assessed. The outcome suggests that the respective pattern of each of the landscapes introduced, contributed immensely to how stakeholders considered as their role in the ES provision.

3.4. Certainty and uncertainty levels of expert assessment

In this study, we focused on individual expert self-assessment of how certain or uncertain they judge their assessment. A detailed account of this evaluation is presented in Fig. 7. The outcome suggests that while half of the respondents were very certain about their judgement, the other half were uncertain. Amongst the 50% uncertain group, the output statistics revealed that only 7% of

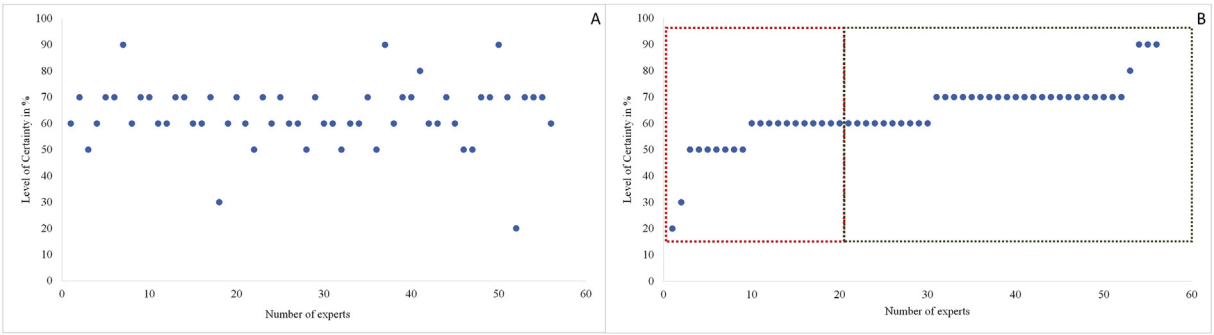

Fig. 7. A graph representing expert's degree of certainty on their evaluation of landscape capacity to provide ES using landscape element as proxies. Inset A represent the scatter with unsorted distributed while Inset B represent a sorted distribution of experts evaluation. From Inset B, lower values enclosed in red rectangle represents very uncertain evaluation while higher values enclosed in green rectangle reflects very certain evaluations. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

experts were very uncertain about their evaluation. Thus, their ratings ranged between 0 and 20%. In a sharp contrast, the remaining 43% of this group provided the 30% evaluation rating that cannot be considered as very uncertain. A possible reason for this variation could be associated with the misunderstanding of the AHP ranking system rather than the ES concept itself. In the case of the latter, some experts were interested in factoring in the role geophysical factors like relief and soils play in determining the observed patterns in our test landscapes.

3.5. Testing resilient scenarios with or without LSM application

Analysis of both scenarios revealed the true significance of utilizing LM in our assessment. A comparison between the LR-1and LR-2 shows differing values and effect for the selected ES. Without LM application, the landscapes had some potentials for ES provision. Figs. 8 and 9 combines the outcomes of the two scenarios according to starting conditions and after effect of the application of LSM in GISCAME.

For example, by comparing landscapes under scenario LR-1, it was clear that before applying LM, L1 had the highest value for flood control and pest and disease control. This could be attributed to the extensive patch sizes of trees, grasslands, and legumes in that particular landscape. In the case of L4, a minimal contribution to climate control at the reference stage of the simulation was observed. L2 produced the lowest contribution to pest and disease control. This is attributable to the over 65% occupancy of grassland patches in that landscape. Distinguishably, L3 was found to provide average contribution across all four ES. Under the reference scenario of LR-2, L4 was found to have a considerably high value for pest and disease control as well as flood control. L3 also contributed minimally to the provision of wind erosion control and climate control. This could be attributed to the high share of settlement patches on that landscape. In a sharp contrast, L1 appeared the highest contributing landscape to wind erosion control. L1 and L4 had similar contribution capacity to flood control.

In the next overview, we sought to see how the application of LM in the Landscape Structure Module will alter the landscapes potential to provide ES under both scenarios. A significant increase in landscape potential to provide ES was observed for L1 under LR-1 in Fig. 8. It could be said that the extensive structural heterogeneity of land use types influenced the observed outcome. However, in the case of L3, we observed marginal improvement across all ES except flood control. While some improvement could be observed for wind erosion control and flood control for L4, a more significant increase in climate control was observed. A minimal increase in the potential to provide flood and wind erosion control was also observed for L2.

Compared to LR-1, LR-2 when tested revealed a much improved landscape potential. For instance, while there were improvement in landscape capacities across all landscapes in LR-2, we did not find significant decreases for any specific landscape. For example, under LR-2 scenario, a significant improvement in all ES was observed for L1 while L2 was characterised by a marginally observable improvement. For both landscapes, there was no relevant decrease. From Fig. 9, a minimal increase in flood control and pest and disease control was observed for L4. Nonetheless, a significant increase in wind erosion control and climate control is visible for the same landscape.

4. Discussion

The application of LM, AHP, and Likert Scale through multi-criteria evaluation approach through GISCAME in our proposed framework helped to explore and explain, for the first time, the structural relevance, and capacities of agriculture-dominated landscapes to provide regulating ES in West Africa. However, in the absence of agricultural landscape management regulations and policies **from** our study area, several assumptions were made to showcase the strength of our assessment framework **as a means** to provide additional information for the study location and **serve as basis** for replication across landscapes within the WASCAL project area.

Our case study focused on the capacity of **an** entire landscape **to** provide regulating ES. This differs slightly from other studies which focuse**d mainly** on the element within the landscape (see Burkhard et al., 2009) while ignoring the totality of the landscape proper to influence ecosystem service provision **and** shape landscape resilience.

The outcome of our AHP (see Table 9) suggests that, landscape L3, characterised by a fair distribution of **all nine land use types from** our case study area, substantively came up as the best landscape pattern to **ensure** flood control. This was found to be in line with part of the key roles played by mixed agricultural patches **by** intercepting surface runoff across agricultural landscapes (Albalawneh et al., 2015). It must be emphasized that similar to the overall weighting of L3 as the landscape with the highest capacity to influence the provision of wind erosion control, expert's weightings were **applied** without factoring in **the role of** geophysical factors such as relief and soil types as key determining factors to this evaluation.

For the most part, a fair justification **resides** on the absence of biogeophysical data which could be modelled and later coupled to this assessment approach to facilitate a better judgement and performance of the overall outcome. By far, the **absence** of dominant patches of any land use type, **coupled with** the structural juxtaposition of landscape element in landscape L4 could be the reason **for it high rank in** favour of pest and disease control. Agricultural landscapes with diversified plant species has been found to promote crop pest and disease control (Ratnadass et al., 2012). That notwithstanding, current practices of expanding agricultural land in relation to settlement and population change (Kleemann et al., 2017), could have both positive and negative consequences going forward.

The application of Likert scale as an expert based assessment approach for assessing the provision of ES is not new (Koschke et al., 2012; Lamarque et al., 2014; Burkhard et al., 2015), even though the approach as adopted for our specific case study area is new. Apart from being a major **source of data in the absence of modelled data,** Burkhard et al. (2015) **cautioned,** that the approach could be characterised by uncertainties and or unexpected results resulting from the involvement of stakeholders in the ecosystem studies (Menzel and Teng, 2009). The main challenge in our expert stakeholder approach bordered on which expert to contact, how to contact them and how often to establish **this** contact. The unavailability of experts, coupled with time constraints, inhibited the possibility of expanding our group and employing the Delphi approach for our stakeholder consultation. Adaptation to the challenges offered a simplistic way to compare across all four landscape the influence of the landscapes patterns on ES provision. In the end, the result of this expert approach revealed that L3 received the strongest prioritisation for the provision of all four regulating ecosystem services (see Fig. 6 variability of L3 in comparison to the other landscapes on their levels of capacity to provide some ES).

Comparing the output between AHP and Likert scale, some **consistencies** in the results were observed. Both AHP and Likert scales prioritized landscape L3 as the most dominating landscape with the capacities and potential to provide all four regulating services. For the most part, stakeholders found it much easier to

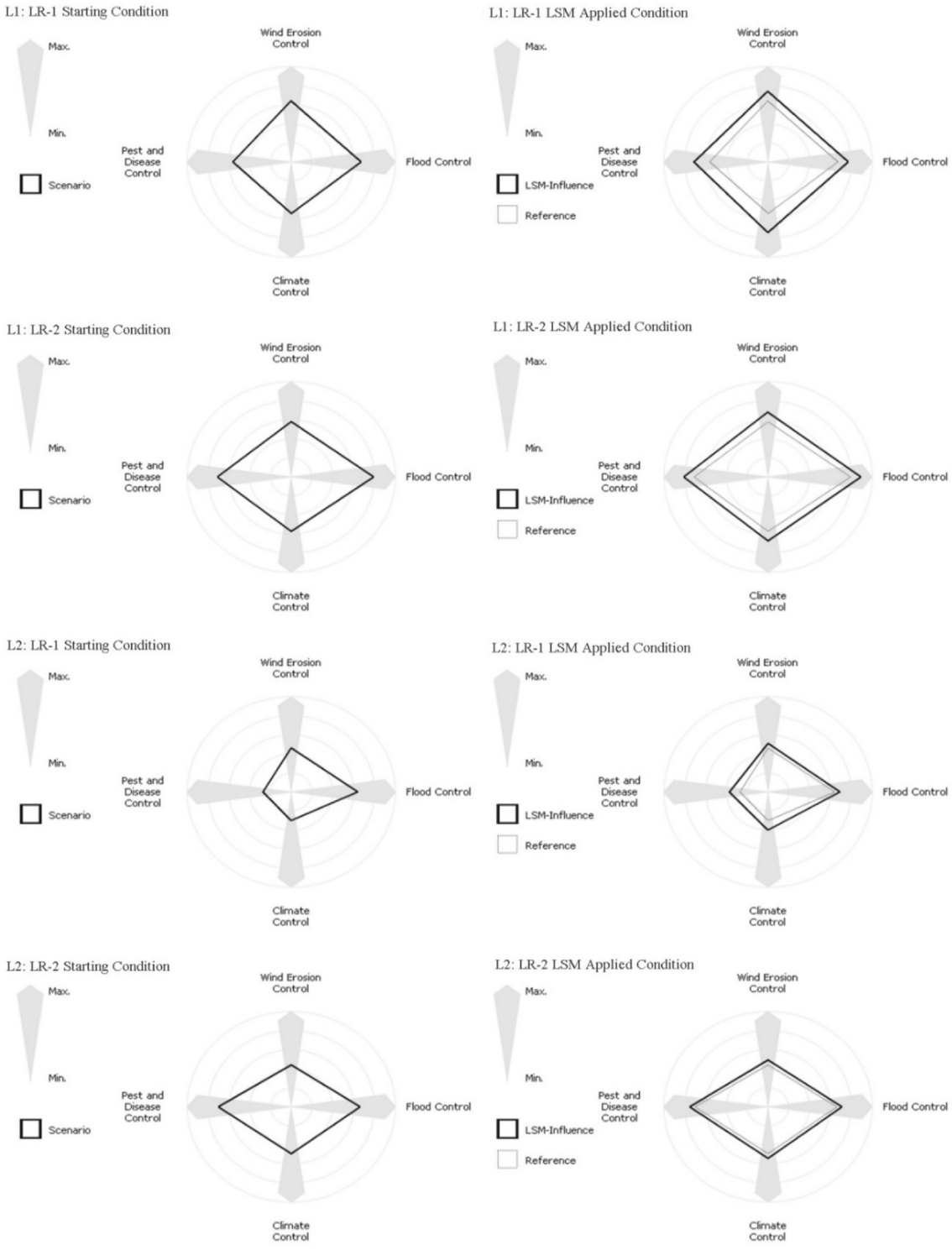

Fig. 8. Outcome of spatially explicit testing of landscape resilient scenario LR-1 as well as LR-2 for L1 and L2. The reference situation of the scenarios are showed in solid thick black lines, while simulated outputs are displayed in dash black lines.

handle the Likert scale approach better than the AHP. The reason for this ease could be associated with the time researchers took to explain in detail the concept of ecosystem services, regulating ecosystem services, and the expert approach employed. Compared to the Likert scale approach, stakeholders had it challenging to first understand, and further provide their feedbacks as expected. The challenge with the use of the AHP approach can be associated with the core understanding to the numerical association of a landscape over the other under a specific criterion (in this case ecosystem services). We found that this was common in the application of AHP as both Koschke et al. (2012) and Albalawneh et al. (2015) outlined similar challenges in line with what was experienced in our study. This notwithstanding, a conscious effort to fully explain the AHP process could have unearthed some in-depth information to ensure

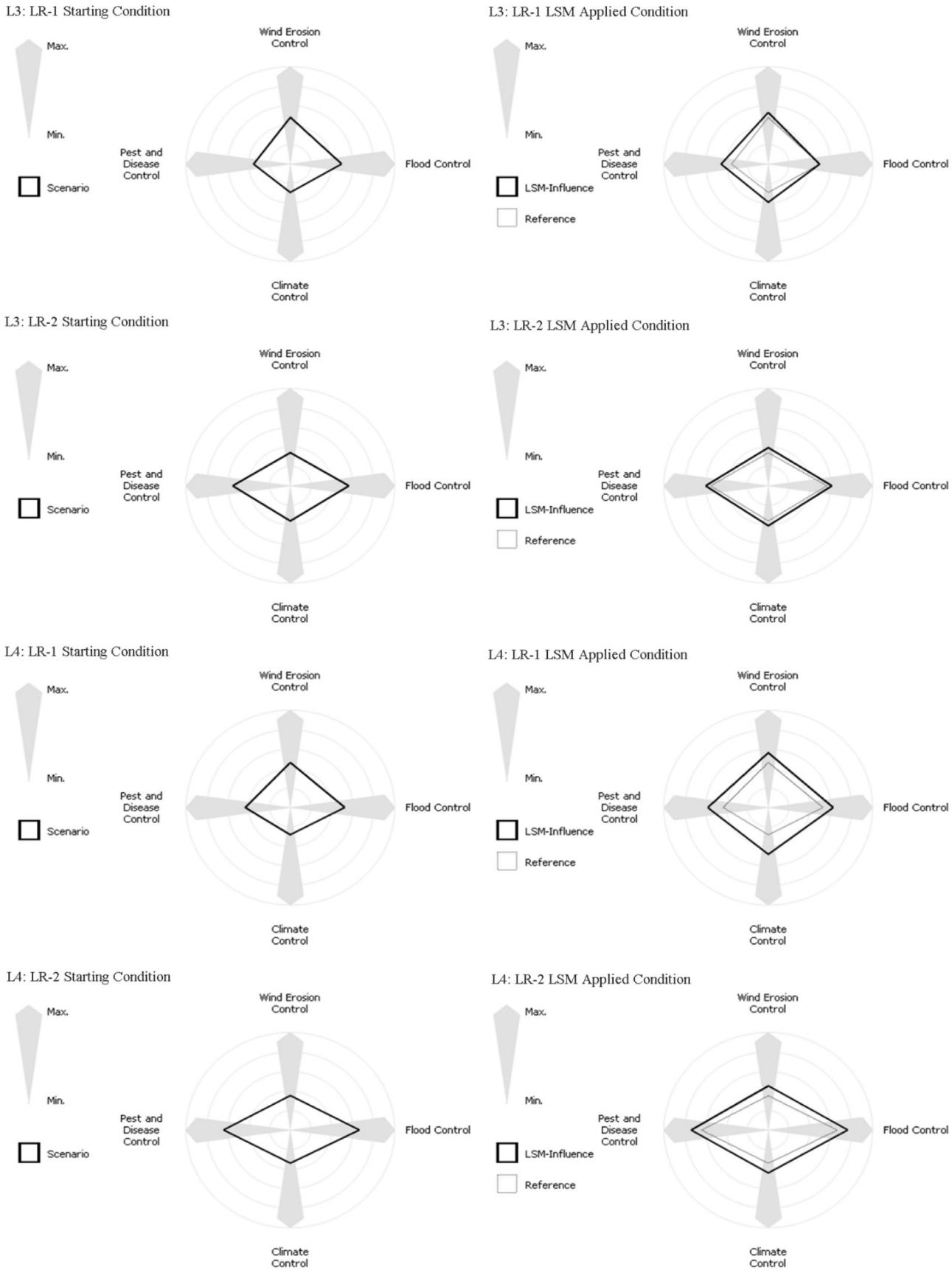

Fig. 9. Outcome of spatially explicit testing of landscape resilient scenario LR-1 as well as LR-2 for L3 and L4. The reference situation of the scenarios are showed in solid thick black lines, while simulated outputs are displayed in dash black lines.

maximum consistency in the outcomes across board. This statement comes on the grounds that many stakeholders were eager to learn how the approach could be extended to other ES not considered in this research. This outlines the interest to not only learn, but to explore what information could be obtained from the use of this approach in the subregion.

Uncertainties have been associated with the number and selection of experts into the evaluation process (Hou et al., 2013). However, a usual number of 50 respondents with valuable knowledge on the topic for evaluation (Koschke et al., 2012) could serve as a caveats to increase certainty and reduce uncertainty margins. This was exactly the case for our study location (see Fig. 7). Nonetheless, apart from it ease and quick qualitative response rate, the use of this approach and result could be significantly improved. Since the uncertainties **arose** from unfamiliarity's and challenges with the AHP **approach**, **additional** time **is needed to** educat**e** expert on the essential differences o**f** the 9 ranking categories proposed by Saaty (1977). A connection of these categories to the issue under deliberation should be emphasized. Other alternative methods in the form of Delphi approaches could be employed to eliminate, if not reduce, the uncertainty and to help improve reliability, transferability, and accuracy of responses and results from these approaches. Again, mixed method approaches (Kleemann et al., 2017) employed to compare expert and modelled results could be employed.

Even more revealing was the outcomes of the resilient scenario where the **role of the** structural **landscape** mosaic became apparent. This, coupled with the impact resulting from the landscape metric approach gave precedence to the most negligible aspect of the landscape mosaic and it role in ES provision. According to Fürst et al. (2012), reclustering land use classes into classes of naturalness (Hemeroby), and applying the landscape metric calculations helps to reveal our limited knowledge of impact of the structural effect on the landscapes' potential to provide ecosystem services. For testing structural relevance, we employed a three staged spatially explicit approach initially suggested in Fürst et al. (2012) and Frank et al. (2012a,b, 2013). This approach represents the first of its kind **implemented** in Sub-Saharan Africa and specifically **on** regulating ecosystem services under the quest **to provide** landscape resilience in the face of changing climate. In our test case, we could prove that the application of the LSM approach in both LR-1 and LR-2 in Figs. 8 and 9 significantly improved the landscapes' capacity to provide ES. Interestingly, the outcome of this exercise gave greater precedence to L1 and L4 as the dominant landscape to provide some of the ES. The result of this task proved that the predominantly diversified agricultural landscapes and their patterns provides a considerable knowledge **to influence** management practices and decisions not only at the landscape scale, but equally at the regional management levels. We agree with Frank et al. (2015) that the result of such research should be adapted to governance models on the land management of biophysical properties, and spatial prioritisation strategies across planning scales. In relation to planning for example, Fürst et al. (2012) affirmed that employing stakeholder or expert knowledge provides the enabling environments for formulating regional planning targets which factors in ES provision. While expectations to utilize planning rules and concept to manage agricultural landscapes in our case study area appears inconceivable, we anticipate that our approach and results will facilitate similar thinking and decision to plan, manage, monitor, and consciously regulate landscape structural patterns to improve the landscapes' potential to consistently provide ecosystem services and ensure landscape resilience.

5. Conclusions

This study, for the first time in the West African sub-region, sought to develop a framework for assessing the relevance of landscape structural patterns on the ES provision. The idea for this framework was due to the absence of methods and approaches tested within the sub-region for replication. Thus, the study employed specifically expert based weighting approaches including approaches, specifically, Analytical Hierarchical Process (AHP) and Likert scale ranking approaches, to facilitate experts' assessment of the landscapes' capacity to provide ES. Additionally, the study explored the linkage between spatial multi-criteria evaluation and landscape metric approaches already existing in GISCAME to understand the role landscape structure plays in potential ES provision at the landscape scale.

The outcome of our approach provided a vivid information on the potential benefit and contribution of the more dominant agrarian landscapes in the Upper East region towards regulating ES provision. For instance, the identification of L3 through the expert approach, and the mixed conclusion on L1 and L4 as the most resilient landscapes provide the needed input for stakeholders in Ghana's agriculture, including the Ministry of Food and Agriculture, household farmers, and other researchers to factor in the landscapes' structural dynamics in their planning and policy considerations. In another respect, the outcome of the study opens additional avenues for employing the framework and similar approach in landscape and spatial planning across levels (local, regional and national). The valuable input of this approach to regional and spatial land use planning considerations (Fürst et al (2010a,b, 2012); Frank et al., 2012a,b). has been enormously received by policy makers and researchers within this current decades. For developing countries like Ghana, lessons drawn from this approach only makes it easier to compare different landscapes across different regions, and provide the deficit outcomes as inputs for policy consideration in the ongoing Ghana National Spatial Development Frameworks (NSDF; GNSDF (2015–2035)) led and implemented by the Town and Country Planning Department. Across the subregion, areas of similar landscape characteristics across countries could be compared and lessons shared to improve livelihoods and promote environmental sustainability on one hand, and human welfare on the other.

Several challenges, particularly in relation to data accessibility (in good temporal and spatial resolution (see Forkuor et al., 2014) particularly as input for the multi-criteria evaluation and landscape metric assessment may arise. Nonetheless, a consideration for the use of neutral landscape models to test which spatial mosaics could provide which levels of ES, as an inputs for planning could be highly considered (see Inkoom et al. 2017b).

6. General outlook

The framework development and outcomes of this study forms part of an ongoing research to establish an integrated assessment framework to assess the implications of different land use scenarios for the provision of different ES for proper land use and land management in West Africa, with focus on the Upper East Region of Ghana. Therefore, the methods and results presented here, though piloted on regulating ES, test the replicability of our approach within the WASCAL project area. Moving forward, we anticipate that our methods will be extended to other ES types **including** provisioning and cultural services. Further progress could be made by blending stakeholder consultation with biophysical modelling to identify the contribution of multifunctional land uses to provide biological pest control and nutrient cycling regulation from agricultural landscapes, tourism, recreation and mental health from

urban landscapes in the region. However, with the predominantly agrarian character of the study region, provisioning services such as food, fodder and raw material production and supply could be targeted while landscape aesthetics, tourism and spiritual experience and sense of place could be considered under cultural services. Additionally, for structural considerations, the landscape structural module (LSM) in GISCAME could utilize the core set of landscape metrics identified by Inkoom et al. (2018) for the West African landscapes. Here, it is critical to identify thresholds for individual or a combination of LM when applying the LSM module as a proxy to assess the landscape's capacity for potential ES provision.

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